BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

0052 Listing of all figures:

0053 FIG. 1 is a schematic diagram showing one preferred embodiment of the present invention, in which an outer diameter measurement device is located immediately above the furnace and provides the outer diameter data of the preform to the control system; an outer diameter measurement device is located immediately below the furnace and provides the outer diameter data of the bare fiber to the control system; and an outer diameter measurement device is located immediately above the coating device and provides the outer diameter data of the finished bare fiber to the control system.

0054 FIG. 2 is a schematic diagram showing another embodiment of the present invention, in which an outer diameter measurement device is located immediately above the furnace and provides the outer diameter data of the preform to the control system; an outer diameter

measurement device is located immediately below the furnace and provides the outer diameter data of the bare fiber to the control system; and an outer diameter measurement device is located within a shrinkage range of 0.5%~0.3% above the coating device and provides the outer diameter data of the bare fiber with estimated finished diameter error range within 0.5% ~ 0.3% to the control system.

0055 FIG. 3 is a schematic diagram showing a further embodiment of the present invention, in which an outer diameter measurement device is located immediately above the furnace and provides the outer diameter data of the preform to the control system; and only one bare fiber outer diameter measurement device is located immediately above the coating device and provides the outer diameter of the finished bare fiber just coming into coating step to the control system.

0056 FIG. 4 is a schematic diagram showing a further embodiment of the present invention, in which an outer diameter measurement device is located immediately above the furnace and provides the outer diameter data of the preform to the control system; and only one fiber outer diameter measurement device is located at a position within a shrinkage range of 0.5%~0.3% between the furnace and the coating device and provides the outer diameter data of the bare fiber with estimated finished diameter error range within 0.5% ~ 0.3% to the control system.

0057 FIG. 5 is another schematic diagram showing a further embodiment of the present invention, in which an outer diameter measurement device is located immediately above the furnace and provides the outer diameter data of the preform to the control system; and one fiber outer diameter measurement device is located at a different position 31 or 32, in which, when the drawing rate is small, detection of the outer diameter is carried out with the measuring device 31 and when the rate is increased, the detection is carried out with the measuring device 32. Alternatively, only one measuring device is used which can move along the optical fiber depending on the drawing rate.

0058 FIG. 6 is a schematic diagram showing another embodiment of the present invention, in which an outer diameter measurement device is located immediately above the furnace and provides the outer diameter data of the preform to the control system; and only one outer

diameter measurement device is located immediately below the furnace and provides the outer diameter of bare fiber just out from the furnace to the control system.

0059 FIG. 7 is a schematic diagram showing one embodiment of the present invention, which includes two on-line outer diameter measurement devices: one outer diameter measurement device is located immediately below the furnace and provides the outer diameter data of the bare fiber to the control system; and another outer diameter measurement device is located immediately above the coating device and provides the outer diameter data of the finished bare fiber to the control system.

0060 FIG. 8 is a schematic diagram showing one embodiment of the present invention, which has two on-line outer diameter measurement devices between the furnace and the coating device: one outer diameter measurement device is located immediately below the furnace and provides the outer diameter data of the bare fiber to the control system; and another outer diameter measurement device is located at a position with a shrinkage range of 0.5% ~ 0.3% and provides the outer diameter data of the bare fiber with estimated finished diameter error range within 0.5% ~ 0.3% to the control system.

0061 FIG. 9 is a schematic diagram showing a variation of an embodiment of the present invention, which includes only one on-line outer diameter measurement device which is located immediately above the coating device and provides the outer diameter data of the finished bare fiber to the control system.

0062 FIG.10 (Prior Art) is a schematic diagram illustrating an improved conventional optical fiber drawing process (ref. to US Patent 5,073,179).

0063 FIG. 11 (Prior Art) is a schematic diagram illustrating a conventional optical fiber drawing process (ref. to James J. Refi, *Fiber optic Cable – A Light Guide*).

DETAILED DESCRIPTION OF THE INVENTION (PREFERRED EMBODIMENTS)

0064 The requirement for a high quality fiber drawing process includes the followings:

- A uniform fiber diameter as industry requires, e.g., usually 125μm for the glass;
- A uniform coating making a coated fiber diameter such as of 250μm;
- Concentricity of fiber glass and coating layers;
- A constant tension to satisfy the mechanical strength and avoid microbending; and
- A high speed process to make high productivity.

0065 The optical fiber diameter is very important to reducing the loss of light transmission. It is an important issue to get high grade optical fiber with the specified optical fiber diameter and needed accuracy of its optical fiber diameter. Most fibers produced have a diameter of 125 μm with deviations of less than 1 μm required for cabling and splicing. Certainly, the smaller the deviations of the optical fiber diameter, i.e., the higher accuracy of the optical fiber diameter, the better the performance of optical fiber is. The optical fiber diameter is effected by many factors during the optical fiber drawing process. The main factors include the furnace temperature fluctuation, the preform diameter fluctuation, the drawing speed by the capstan, and the preform feeding speed. It is well know that in the stable fiber drawing process, the resulting size of the bare fiber relative to the size of the preform is determined by the drawing speed of the fiber relative to the feed rate of the preform as described in the following equation (2):

$$v_d = v_f \cdot (D^2 / d^2) \tag{2}$$

where v_d is the fiber drawing speed, v_f is the preform feeding speed, D is the preform diameter and d is the fiber diameter. It is obvious from equation (2) that the preform diameter is one major factor for determining the fiber drawing speed.

0066 Thus, it is important to have a preform diameter monitor to measure the preform diameter D for securing a high accuracy of the finished optical fiber diameter d during the optical fiber drawing process. It is a main part of this present invention for the robust diameter-controlled optical fiber.

0067 Further, it is noticed that due to the above-mentioned requirement of a high speed drawing process for a high productivity, the preforms become larger and larger in both diameter and length. Suppose a fluctuation ΔD in a preform diameter. In order to maintain the exact same diameter d of the optical fiber, the fiber drawing speed should have an adjustment amount Δv_d and the preform feeding speed should have an adjustment amount Δv_f as follows:

$$\Delta v_d = [v_f \cdot (2D \cdot \Delta D + \Delta D^2) + \Delta v_f \cdot (D + \Delta D)^2] / d^2 \tag{3}$$

which is derived from eqution (2). Thus, when the preform diameter becomes larger, a same deviation ΔD needs a larger adjustment Δv_d of the fiber drawing speed or a larger adjustment Δv_f of the preform feeding speed in order to maintain the exact required outer diameter d of the optical fiber. It proves an urgent requirement for a preform diameter monitor during the fiber drawing process in presence of fluctuation of the preform diameters when the preform diameters become larger.

0068 The location in which the fiber is formed and is mainly changing its size is the furnace zone. Thus, the position to locate a preform diameter monitor should be as near to the furnace as possible. If there is anything to limit the position of the measuring device, it has been that the measuring device should not be directly subjected to a strong radiation light from an upper portion of the furnace to avoid being heated to a remarkably high temperature. This arrangement should reduce the lead-time of the preform diameter data comparing the diameter data at a position in the furnace where the glass is melting and drawing into the fiber. For a high accuracy control, it may save a memory size in the control system.

0069 This preform diameter measurement signal is fed back to both capstan speed control system and preform feeding speed control system during the optical fiber drawing process.

0070 As above mentioned in the summary part, in order robustly to control the finished optical fiber diameter with a very high accuracy, it is necessary to measure the final optical fiber diameter just before the coating step. The reasons are the followings:

1. First, it is the exact finished optical fiber diameter providing an exact bare optical fiber diameter record for the optical fiber products;

2. Second, it can avoid any conventional "ahead" diameter measurement estimation error for the exact diameter of the optical fiber;

3. Third, it can further avoid any measurement error subject to the any effects due to contaminants, bubbles or the like remain in the optical fiber preform over some length as it is drawn, shrinkage, and so on.

0071 This exact finished bare fiber diameter measurement is another part of the present invention for robustly diameter controlled optical fiber.

0072 Because the main diameter change zone for the preform root in forming the optical fiber is the heating zone of the furnace, therefore it is better to have an outer diameter measurement monitor immediately below the furnace in order to reduce signal lag for the control. Thus, if there is anything to limit the position of the measuring device, it has been that the measuring device should not be directly subjected to a strong radiation light from a below portion of the furnace to avoid being heated to a remarkably high temperature.

0073 It is the best to consider all three measurement signals from the preform diameter measurement, the first bare fiber diameter measurement and the second finished bare fiber diameter measurement for generating a fiber drawing speed control signal and a preform feeding control signal.

0074 It can also been seen that to combine the above mentioned first bare fiber diameter measurement and second finished bare diameter measurement signals alone into an overall control signal is better than the method to combine the first bare fiber diameter measurement and the second coated fiber diameter measurement into an overall control signal which described in US Patent 5443610 in order to robustly control the optical fiber glass diameter, i.e., the final bare fiber diameter.

0075 The preferred embodiments of the present invention are described in the following figures with various combinations of the three above-mentioned measurement monitors to produce robust diameter-controlled optical fiber during optical fiber drawing process.

0076 FIG. 1 shows one most preferred embodiment of the present invention, in which the numerical number 1 indicates the preform feeding mechanism; 2 does the preform for the optical fiber; 3 does a drawing furnace; 4 does a fiber cooling distance or a fiber cooling device; 5 does a bare fiber between the furnace and the coating device; 6 does a die for resin coating applicator; 7 does a coated fiber; 8 does a coating concentrity monitor; 9 does a curing device (a furnace or lamps) for the resin; 11 does a final coated fiber; 12 does a coating diameter monitor; 13 does fiber drawing capstans; 14 does proof test (e.g., strength test); 15 does a winding up device for the optical fiber; 10 does a preform diameter monitor; 20 does an outer diameter monitor for the bare fiber; and 40 does an outer diameter monitor for the finished bare fiber.

0077 The preform 2 which is heated and melted in the furnace 3 is stretched under tension to form the optical fiber 11, which is drawn by capstans 13 and is taken up to spool 15 installed in the winding up device.

0078 In FIG. 1, monitor 10 for the preform is located at a safe position immediately above the furnace 3 in order to reduce the time lead; monitor 20 for the bare fiber is located at a safe position immediately below the furnace 3 in order to reduce the time lag; and monitor 40 for the finished bare fiber is located at a safe position immediately above the coating device in order to provide very high accurate measurement of the outer diameter for the finished bare fiber.

0079 Generally, the outer diameter of the preform is gradually reduced in the furnace corresponding to an axial change of the preform temperature (therefore, a viscosity change of the preform material). Further, a size of the shrinking portion of the preform depends on the drawing rate. As the drawing speed increases, the outer diameter of the bare fiber and the fiber temperature at the outlet of the furnace increase. Of course, to control the outer diameter of the finished optical fiber depends on a preform diameter, structural factors of the drawing furnace such as a heating zone length, a size of the furnace outlet, a flow rate and a kind of an inert gas, as well as a bare fiber diameter. Thus, during the fiber drawing process, monitor 10 measures the outer diameter of the preform which is coming into the furnace, monitor 20 measures the outer diameter of the bare fiber which is coming out from the furnace, and monitor 40 measures the outer diameter of the finished bare fiber which is coming into the coating device.

0080 Then, all these measured data are combined into an overall robust control system to form a fiber drawing speed control signal for capstans 13 and a preform feeding speed signal for the preform feeding mechanism 1, respectively.

0081 Thus, an optical fiber having a better accuracy of the outer diameter of the optical fiber is produced. This outer diameter of the optical fiber is robustly controlled.

0082 It can be seen that the present invention is particularly effective in the drawing of the optical fiber at a very high drawing rate which is becoming faster and faster.

0083 Another embodiment of the present invention is shown in FIG. 2, in which three outer diameter monitors above the coating device are monitor 10 for the preform diameter measurement at a position safely and immediately above the furnace 3, monitor 20 for the bare fiber diameter measurement at a position safely and immediately below the furnace 3, and monitor 30 for the second measurement of the bare fiber at a position at which the diameter shrinkage range less than 0.5%. This embodiment is suitable for improving some conventional methods which currently have an outer diameter monitor 30 at that position with a shrinkage less than 0.5% as said in US Patent 5073179. The robust control system obtains the feedback signals from these diameter monitors and controls the fiber drawing speed and the preform feeding speed for producing robustly diameter controlled optical fibers.

0084 The third embodiment of the present invention is shown in FIG. 3, in which two outer diameter monitors above the coating device are monitor 10 for the preform diameter measurement at a position safely and immediately above the furnace 3, and monitor 40 for the outer diameter measurement of the finished bare fiber at a position safely and immediately above the coating device. They provide control system feedback signals to the fiber drawing process control system for producing high quality optical fibers.

0085 The fourth embodiment of the present invention is shown in FIG. 4, in which two outer diameter monitors above the coating device are monitor 10 for the preform diameter measurement at a position safely and immediately above the furnace 3, and monitor 30 at a position with a shrinkage ratio less than 0.5%. The control system collects these measurement data and determines the fiber drawing speed and the preform feeding speed.

0086 A further embodiment of the present invention shown in FIG.5 is to let monitor 30 in FIG.4 can be adjusted based on the drawing speed, high or low. In the embodiment as shown in FIG. 4, it takes time to detect the outer diameter of the fiber which is under increase in its diameter in the case of small drawing rate, whereby a time lag arises in the control. In the embodiment as shown in FIG. 5, when the drawing rate is small, detection of the outer diameter is carried out with the measuring device 31 and when the rate is increased, the detection is carried out with the measuring device 32. Alternatively, only one measuring device is used which can move along the optical fiber depending on the drawing rate. The rest part in FIG.5 is the same as the corresponding rest part in FIG.4, such as monitor 10.

0087 The sixth embodiment of the present invention is shown in FIG. 6, in which two outer diameter monitors above the coating device are monitor 10 for the preform diameter measurement at a position safely and immediately above the furnace 3, and monitor 20 for the outer diameter measurement of the bare fiber at a position safely and immediately below the furnace 3. The control system collects these measurement data and determines the fiber drawing speed and the preform feeding speed.

0088 Monitor 20 has the smallest time lag than monitor 30 (or 31 or 32), especially when the drawing speed is low. Monitor 30 provides a higher accuracy of the out diameter of the optical fiber than monitor 20 when the drawing speed is high. However, monitor 40 has the highest accuracy of outer diameter measurement for the finished bare fiber, i.e., the optical fiber glass diameter.

0089 A further variation of embodiments of the present invention is shown in FIG. 7, in which two outer diameter monitors between the furnace 3 and the coating device 6, but no diameter monitor for the preform diameter measurement above the furnace 3. Here, one monitor is monitor 20 and another is monitor 40 at the same respective positions as above-mentioned. This method can solve the problem which described in US Patent 5443610 in a better way since the monitor 40 can provide a higher accurate measurement of the outer diameter of the finished bare fiber with a less lag time than monitor 12 can in the conventional methods.

0090 FIG. 8 shows another variation of embodiments of the present invention. In FIG.8 monitor 20 and monitor 30 or 31 or 32 have been selected. They are at the positions as above-mentioned respectively. This method can provide the control system a less time lag information of the outer diameter of bare fiber from monitor 20 in addition to the information provided from monitor 30 or 31 or 32. It is really a new method to combine two previous separated conventional methods in order to get a more accurate outer diameter for optical fibers than any one of these two conventional methods individually.

0091 FIG. 9 shows a further variation of embodiments of this present invention. In FIG. 9 the process has only one diameter monitor 40 between the furnace 3 and the coating device 6. This method may be an alternative method with an advantage of accurate measurement of the outer diameter of the finished bare fiber and keeping a record of this specification for the product optical fiber. However, this method has a cost of time lag for the control system.

0092 Finally, FIG. 10 and FIG 11 show two conventional methods of optical fiber drawing process respectively.

0093 FIG. 10 has only monitor 30 (or 31 or 32) for measuring outer diameter of bare fiber at a position at which the shrinkage of the outer diameter is not larger than 0.5% (US Patent 5073179).

0094 FIG.11 shows only monitor 20 for measuring outer diameter of bare fiber at a conventional position immediately below the furnace 3. In this location monitor 20 minimizes the time lag with a cost without an accurate measurement of the outer diameter for the final bare fiber.

0095 Finally, it should be pointed out that for the above-mentioned embodiments of the present invention shown in Figures 1-9, a forced cooling device for the optical fiber may be provided between furnace 3 (or monitor 20 when it is selected in the embodiment) and coating device 6 (or outer diameter measuring device 40 or 30 when it is selected in the embodiment), whereby the cooling distance between them can be shortened and the time lag can be shortened as well. Such a construction is especially preferred since large scaling of the apparatus can be avoided and a prompt response can be obtained.

0096 As described above, according to the present invention, the absolute value of the outer diameter of the optical fiber can be not only measured correctly but also robustly controlled, whereby the optical fiber with better accuracy in its size is produced in face of fluctuations of the preform diameters, fluctuations of the furnace conditions, various disturbances and parameter perturbations, especially in a high productivity situation with increasing drawing speed, enlarging preform size and raising high performance of optical fiber during the optical fiber drawing process. Thus, this present invention provides robust diameter-controlled optical fibers during optical fiber drawing process.

Cover Sheet

Attention : John Hoffmann

Sender : Ben Wang , 919-656-0638
(fax) 919-543-8228

Subject : Paper for Dr. Shengguo Wang

Attached : Letters from Dr. Wang 3 pages

Revised paper 30 pages

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June 1, 2004

Mr. John Hoffmann
Primary Examiner
Art Unit 1731
United States Patent and Trademark Office
Alexandria, VA 22313-1450
571-272-1191
571-273-1191 (F)

Re: Sheng-Guo Wang's Patent Application 09/989,799

Dear Mr. Hoffmann:

Following our today's talk, I am faxing you the followings that were mailed via the US Post Service (mail track label number: 7003 3110 0005 1005 9034) on May 14, 2004, and again via the Worldwide Express Mail Service (mail number: EA543877125CN) on May 27, 2004:

1. Letter of May 14, 2004, to the Examiner for my Election;
2. Letter of May 14, 2004, to the Examiner for the revised Specification (No New Matter to Be Added);
3. A clean version of the revised Specification (No New Matter to Be Added); and
4. A marked-up version of the above revised Specification to indicate the changes on the original Specification.

Because I am out of the country for an international conference, therefore I am sending my fax from the oversea.

Thank you very much for your advice and consideration of my application.

Very truly yours,

Sheng-Guo Wang
(704) 503-0747

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May 14, 2004

Mr. John Hoffmann
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Art Unit 1731
United States Patent and Trademark Office
Washington, DC 22313-1450

Re: Sheng-Guo Wang's Patent Application 09/989,799

Dear Mr. Hoffmann:

I have received your Office Action — Election/Restrictions, mailed on May 3, 2004, in view of two different inventions: (i) a method and (ii) a fiber.

I agree with you. Following your Office Action, I choose the method for my election to the restriction requirement.

Therefore, I elect Claims 1-5, 7-10, 12-15 and 17-19 in the application.

Thank you very much for your advice and consideration of my application.

Very truly yours,

Sheng-Guo Wang
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May 14, 2004

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Re: Sheng-Guo Wang's Patent Application 09/989,799

Dear Mr. Hoffmann:

Thank you for your Detailed Action mailed on May 3, 2004, with the guidelines to illustrate the preferred layout for the specification of a utility application.

Following your guidelines and advice, I am enclosing my Revised Specification by removing those mentioned items – (No New Matter to Be Added) as follows:

1. A clean version of revised Specification (No New Matter to Be Added), and
2. A marked-up version of the above revised Specification to indicate the changes on the original Specification.

I summarize my revision as follows:

1. To remove the Table of Contents (previous page 3);
2. To remove everything on the previous page 4;
3. To remove most of page 1;
4. To move the Abstract of the previous page 2 to the end of the Specification;
5. To correct 5333610 (a typographical error) to be 5443610 in the previous page 9; and
6. To elect Claims 1-5, 7-10, 12-15 and 17-19 for the Election/Restrictions; and
7. To do the corresponding new page-numbering of the revised Specification.

Again, thank you very much for your advice and consideration of my application.

Very truly yours,

Sheng-Guo Wang,
(704) 503-0747

Enclosures